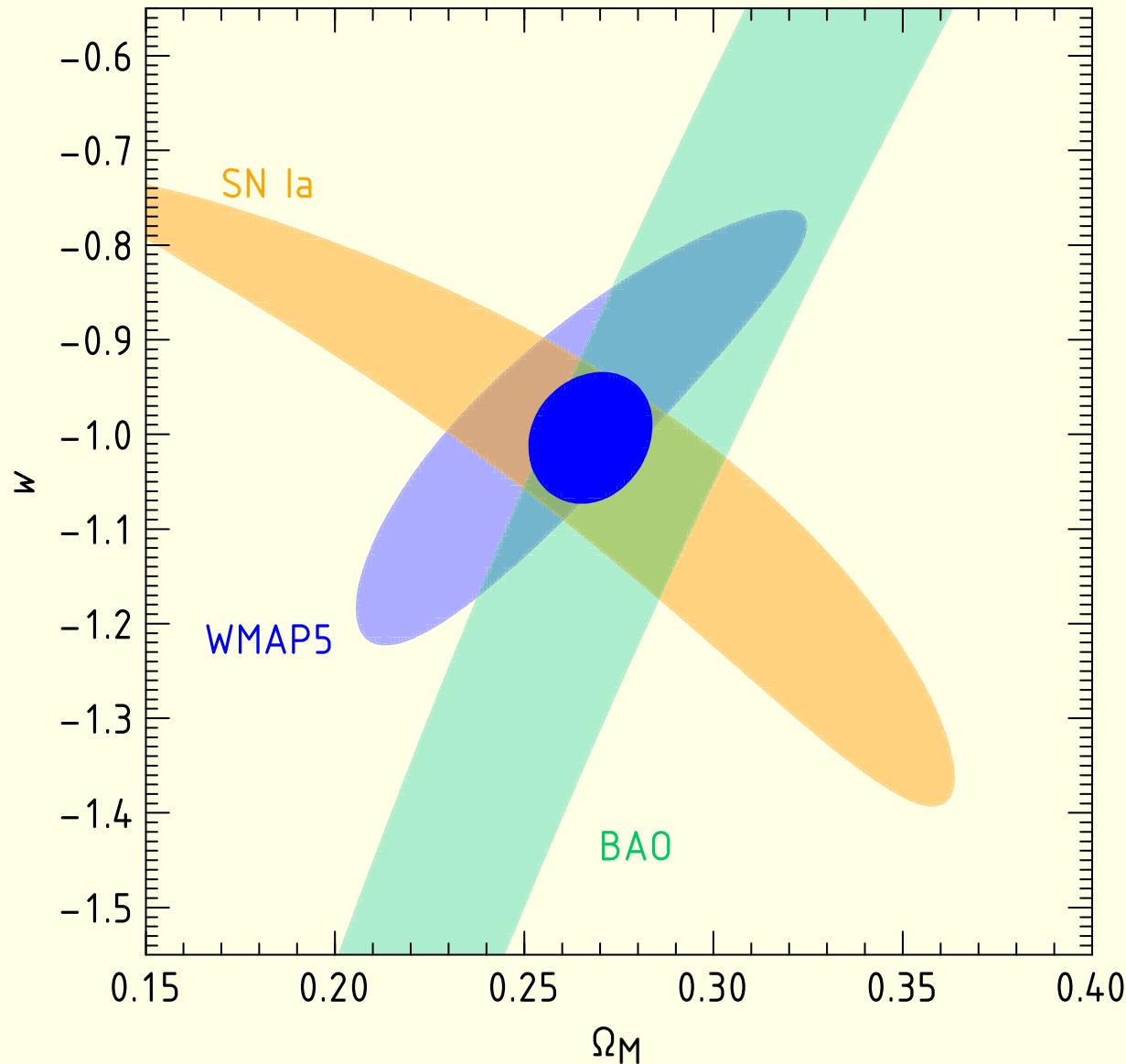
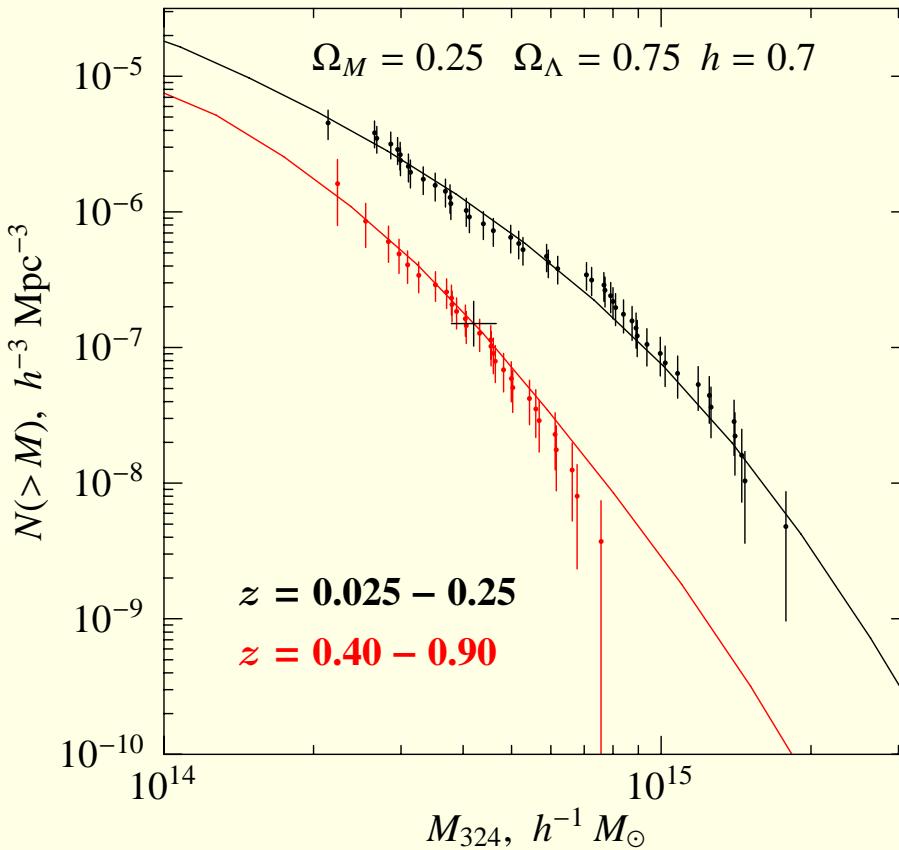


X-ray cluster surveys



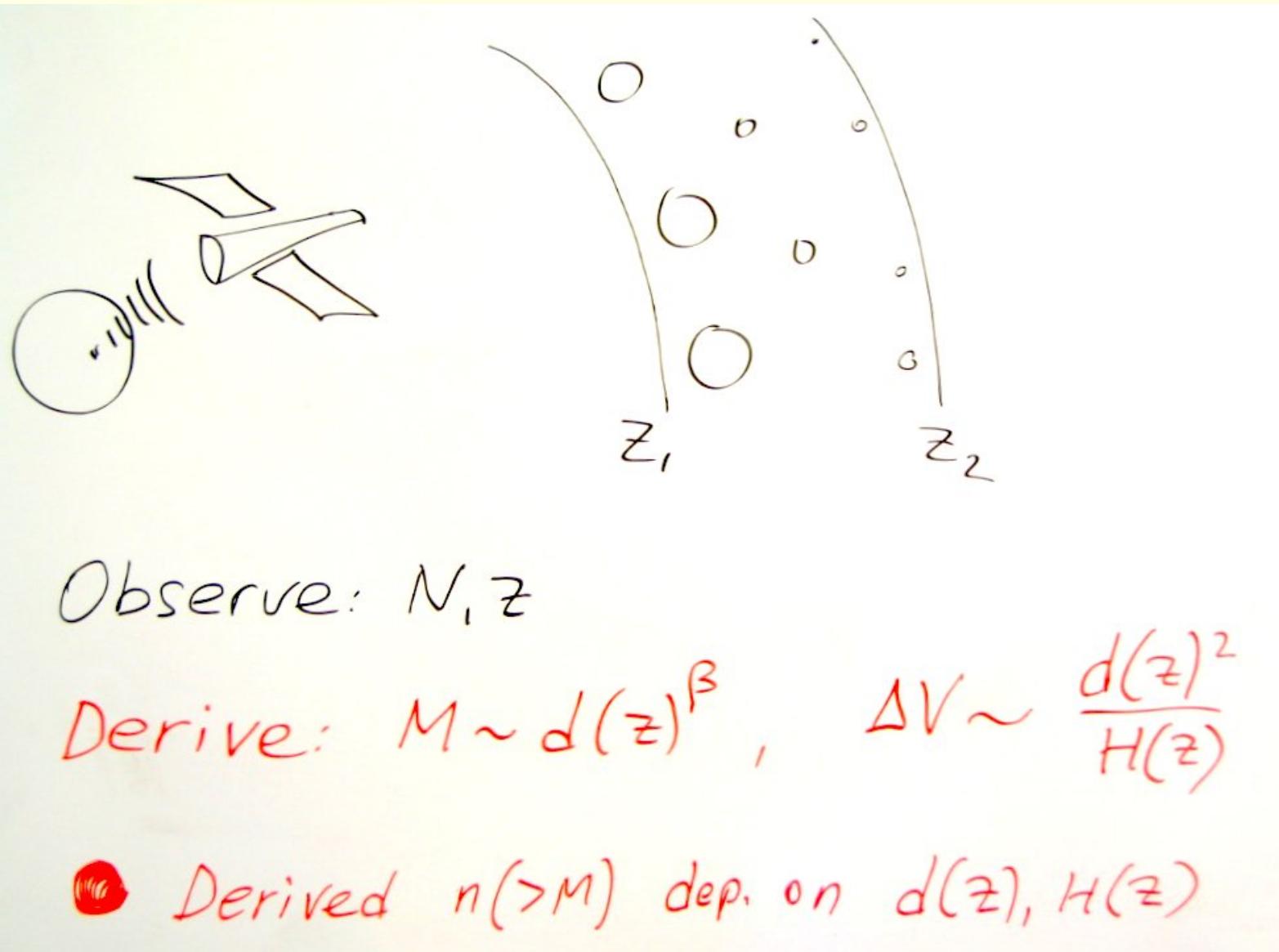
Alexey Vikhlinin

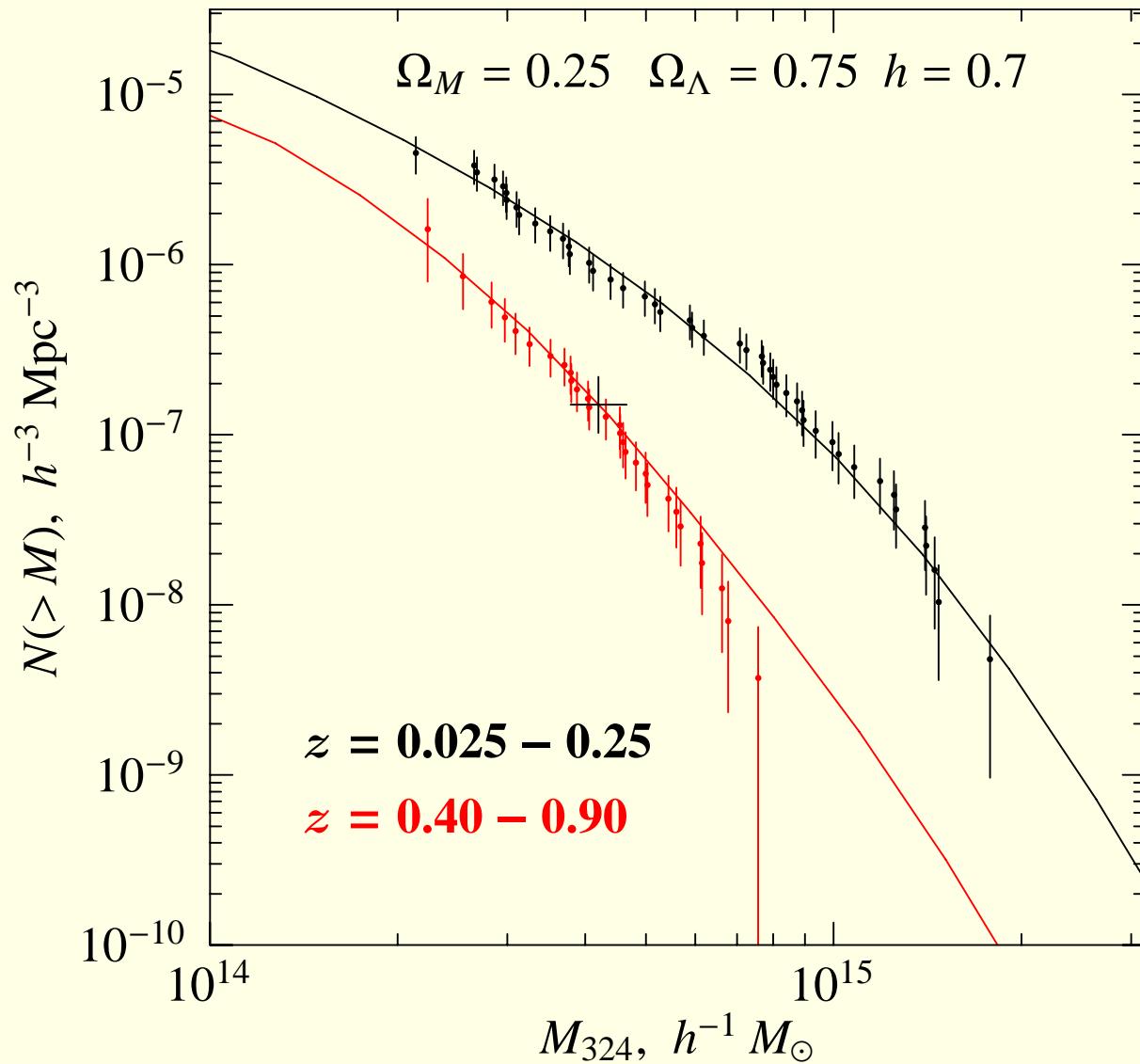
Info from cluster mass functions

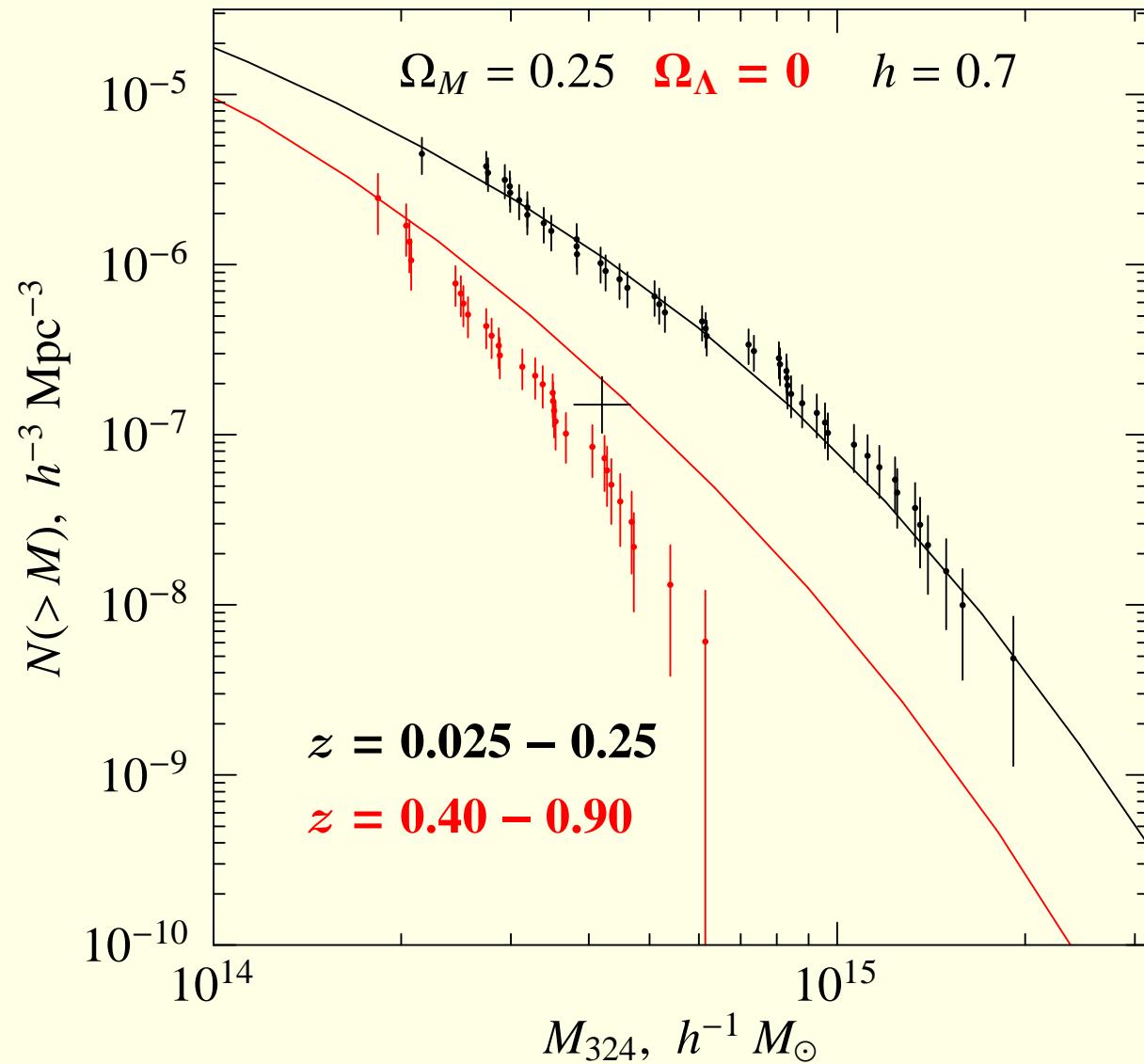


- Shape $\longrightarrow \Omega_M h$
- Normalization $\longrightarrow \sigma_8$
- Evolution $\longrightarrow G(z) [+d(z), +E(z)]$

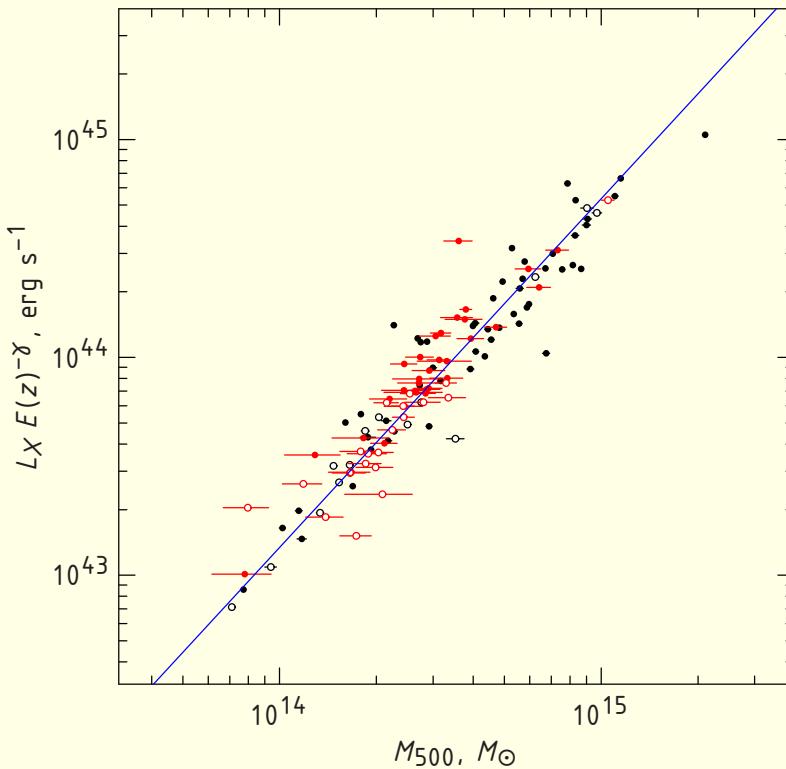
Role of $d(z)$ and $H(z)$ in mass function test





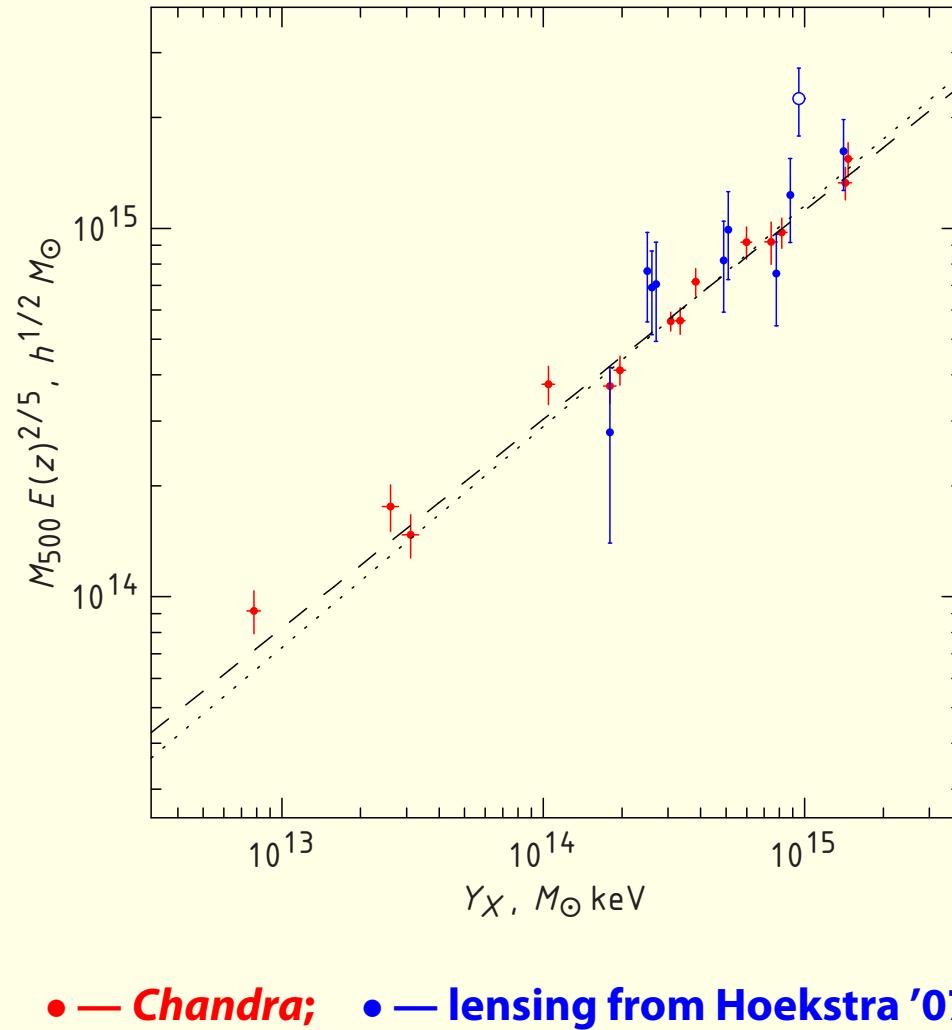


Mass proxies: L_X — not to be used blindly



- Large scatter
- wrong slope
- dominated by cluster centers
- *self-calibration: $dN/dL + P(k) + \text{shape} \Rightarrow M$*

Better mass proxies: T_X , M_{gas} , Y_X



- T_X : $M_{\text{tot}} \approx A T^{3/2} E(z)^{-1}$
- M_{gas} : $M_{\text{tot}} \approx B M_{\text{gas}}$ [$B = B(M, z)$]
- $Y_X = T_X \times M_{\text{gas}}$: $M_{\text{tot}} \approx C Y_X^{3/5} E(z)^{-2/5}$

$$\Delta M/M < 9\%$$

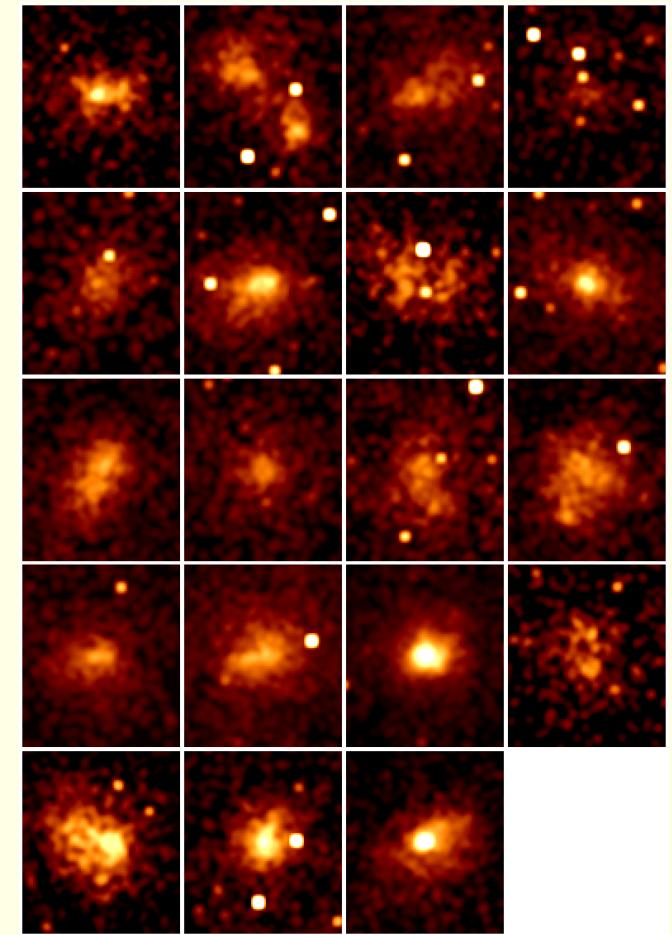
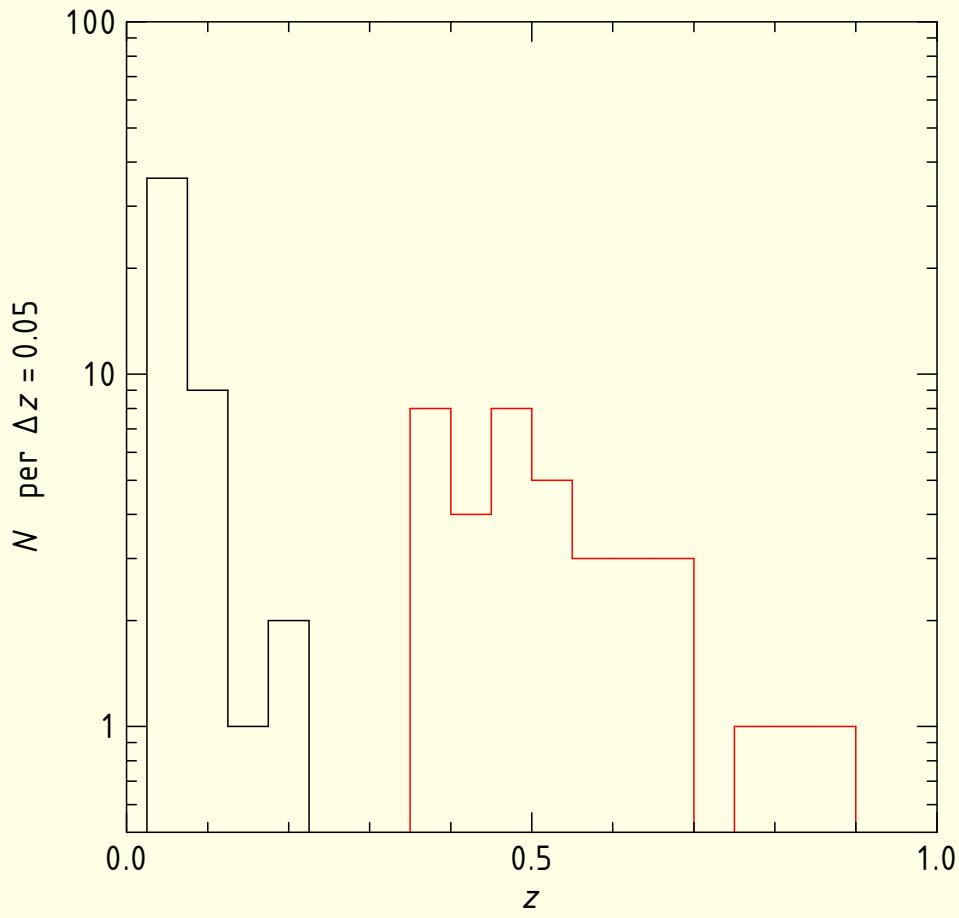
Cluster samples

- 41 at $z > 0.35$ from 400d

<http://hea-www.harvard.edu/400d>

- 48 at $z \sim 0.05 - 0.15$ from ROSAT All-Sky Survey

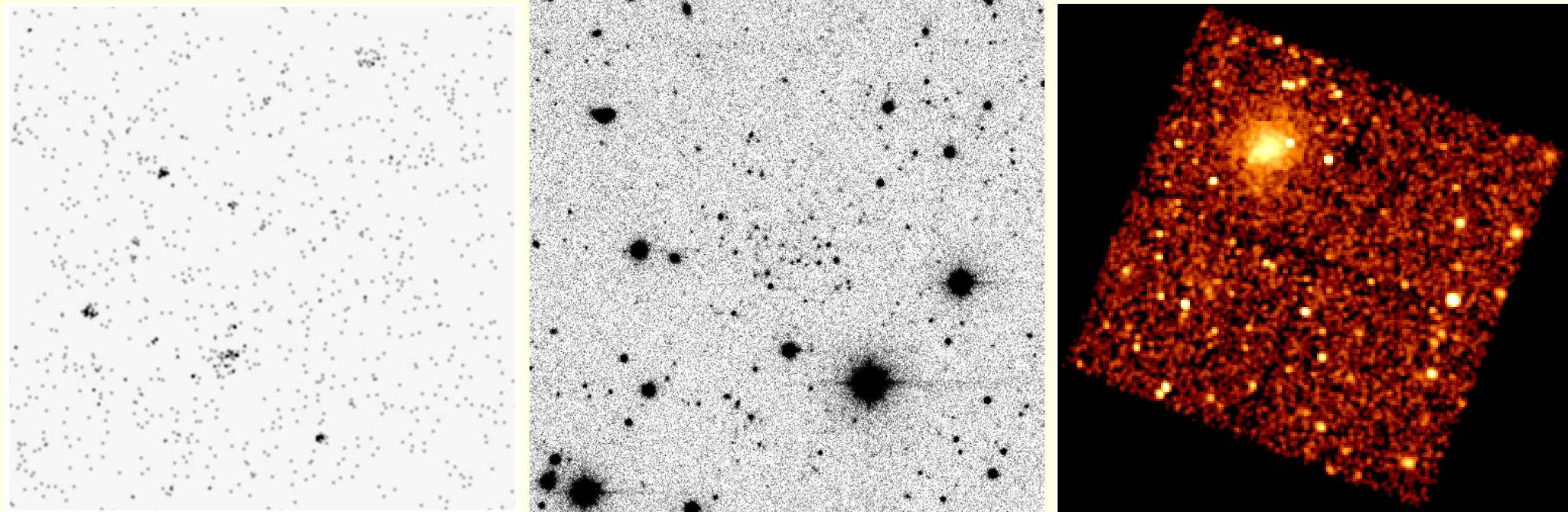
(*Chandra* archive)



- Volume = $3 \times V(z < 0.1)$

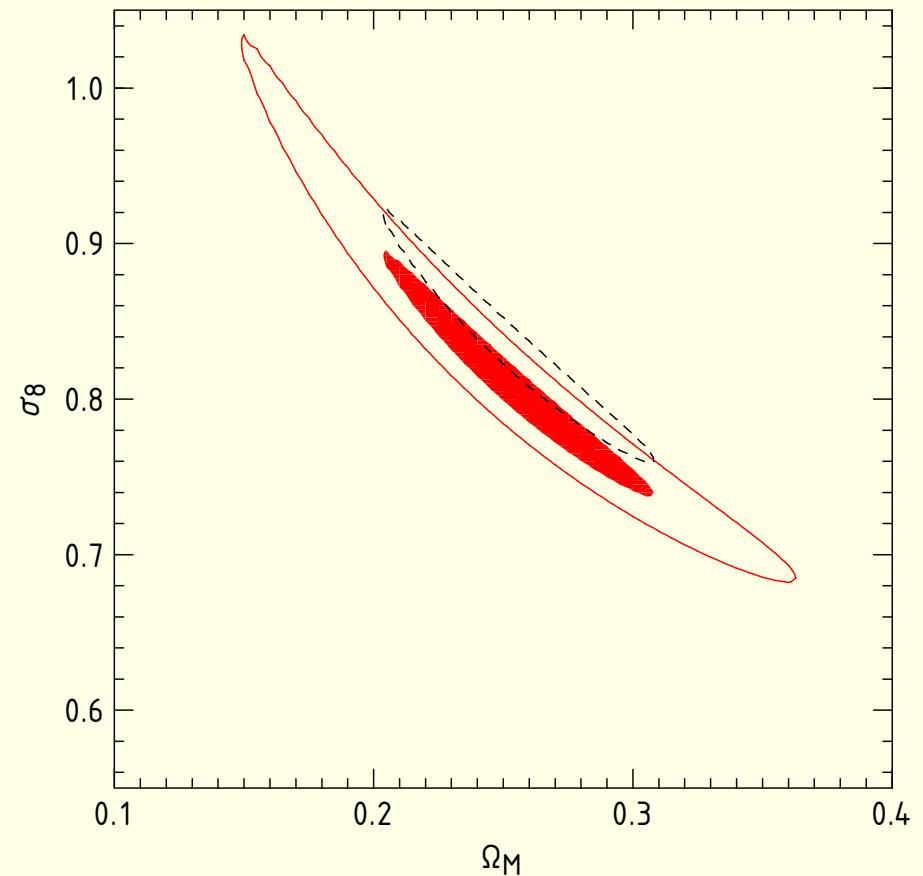
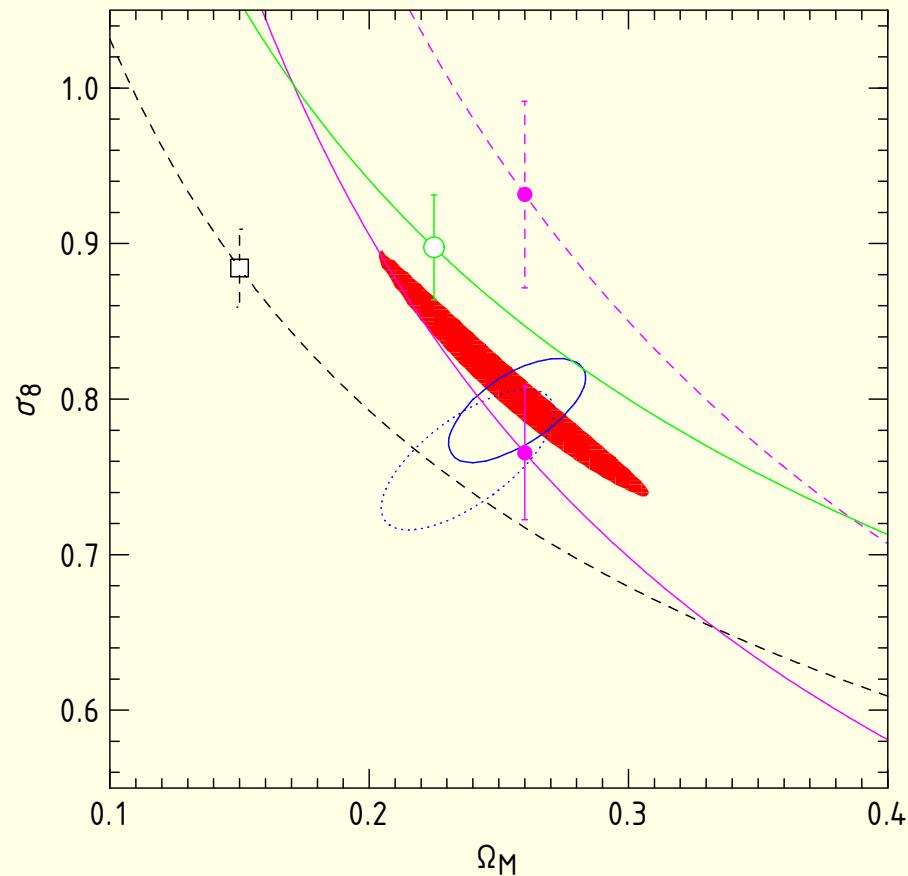
400 deg² *ROSAT* high-z Cluster Survey

Detection in X-rays → Optical ID → *Chandra* observations



- Will be easy with SRG/e-Rosita
- Requirements for self-calibration are demanding

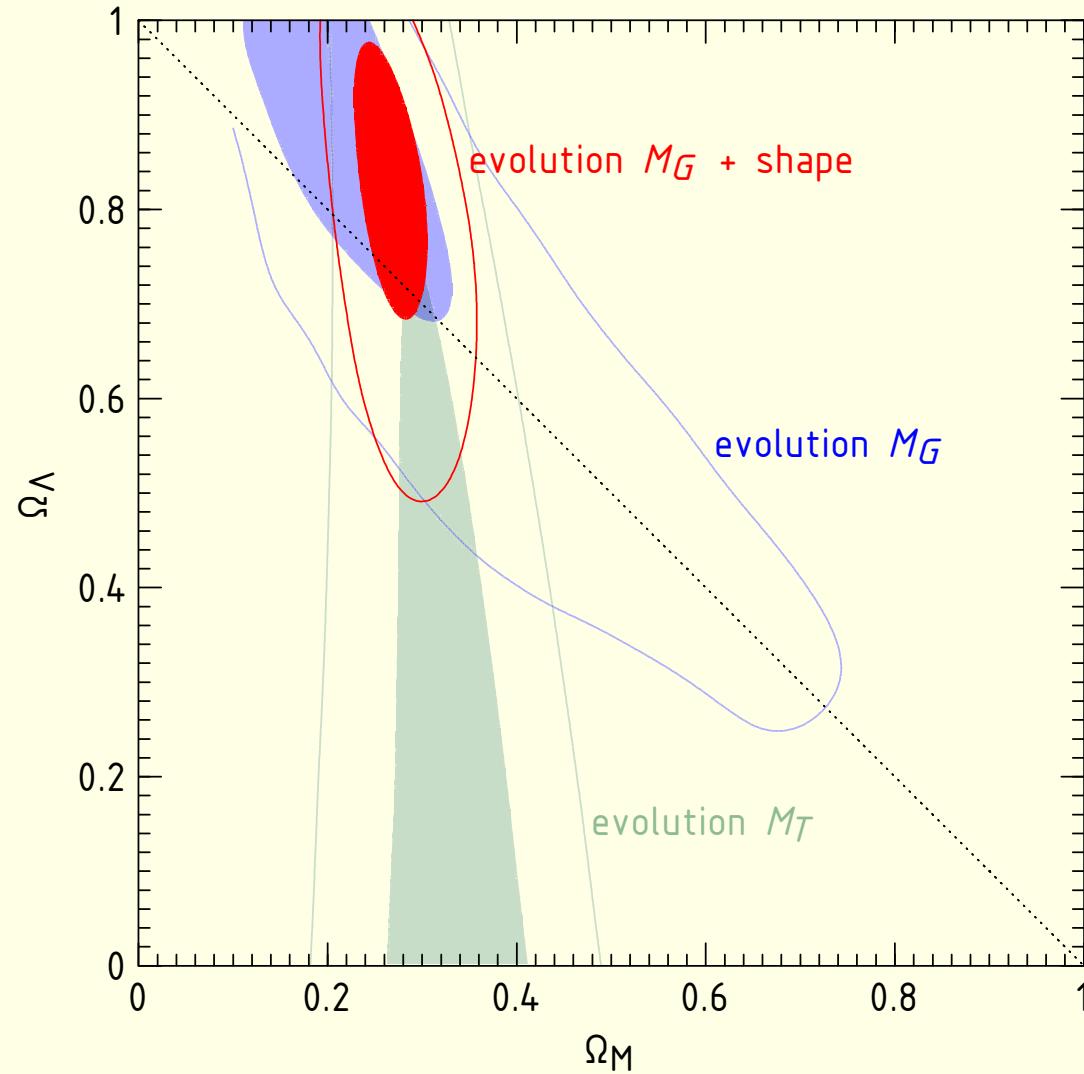
σ_8



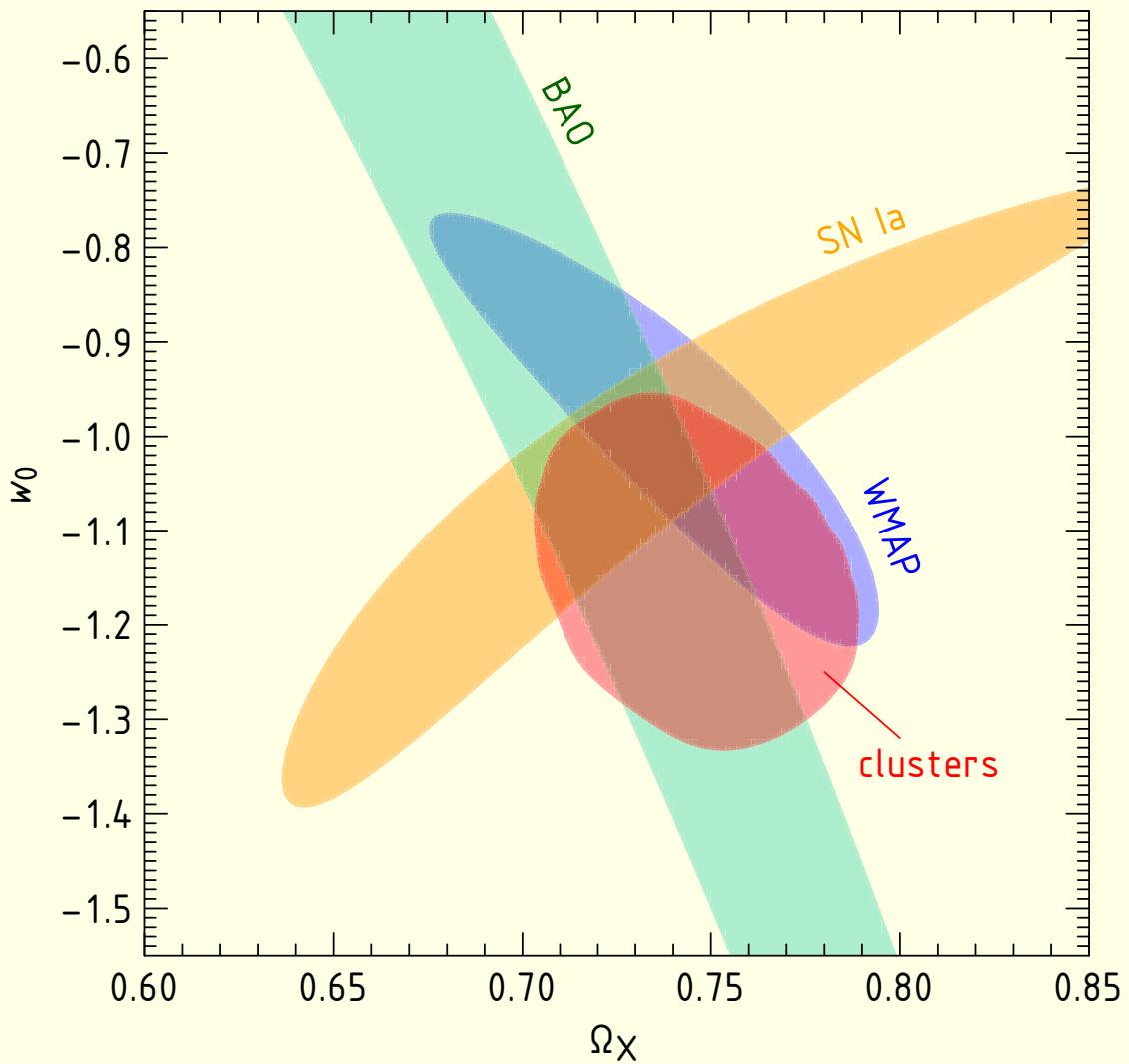
WMAP; weak lensing shear; old X-ray clusters; clusters, kinematic masses

For $\Omega_M = 0.25$: $\sigma_8 = 0.813 \pm 0.013$ (stat) ± 0.024 (sys)

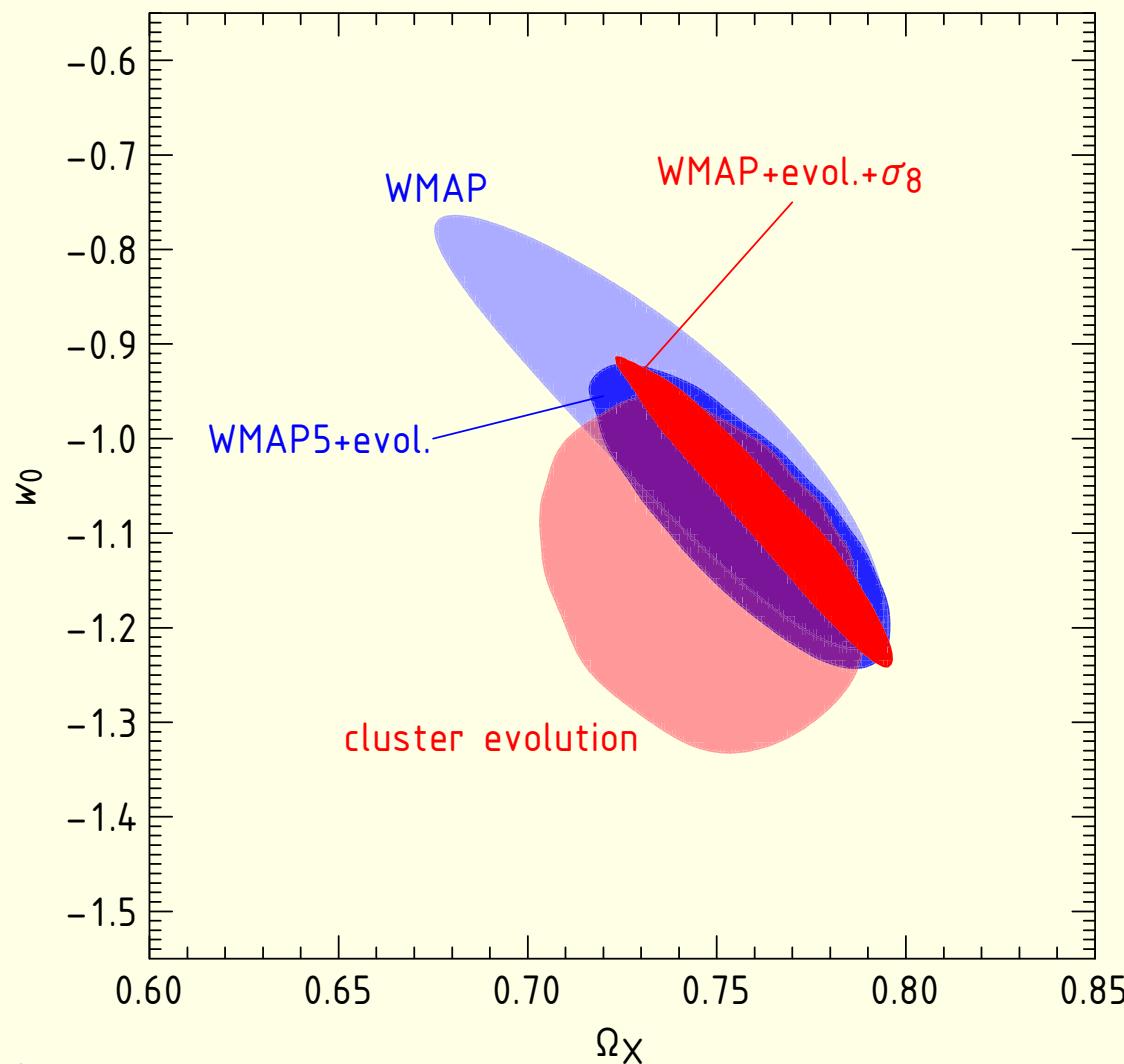
$\Omega_M - \Omega_\Lambda$



Dark energy constraints



Dark energy constraints: CMB + clusters

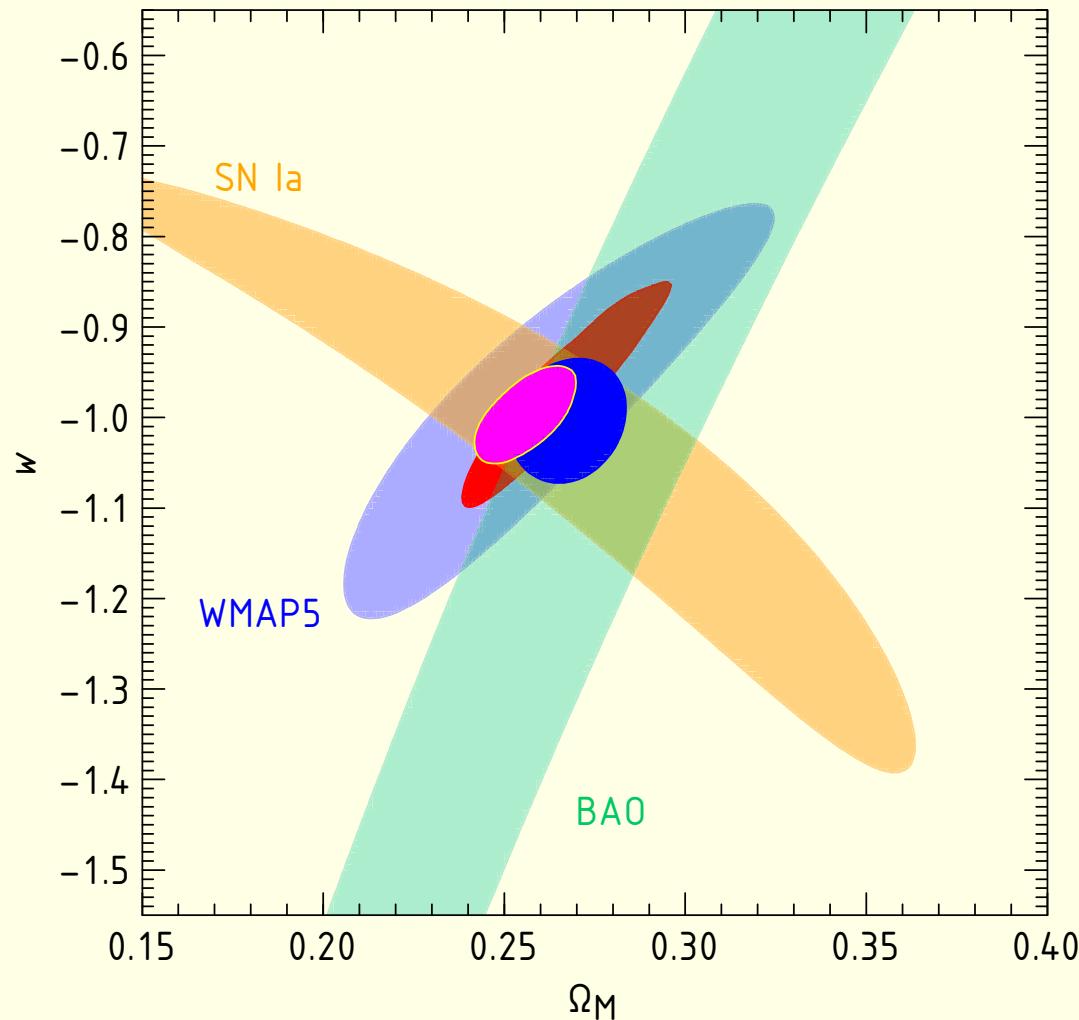


Systematic error budget:

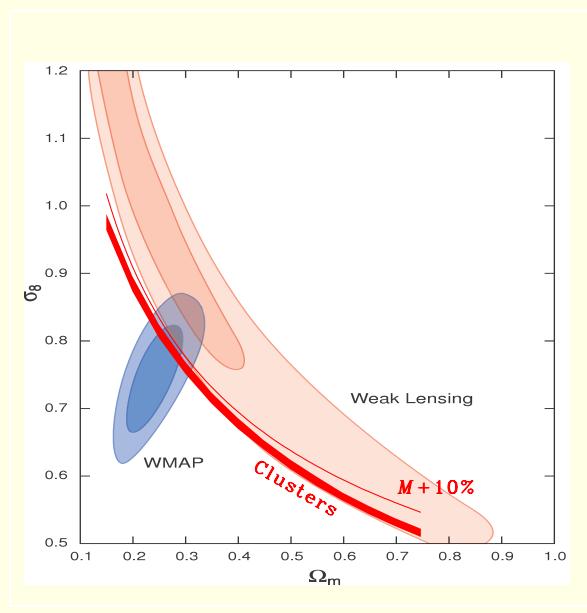
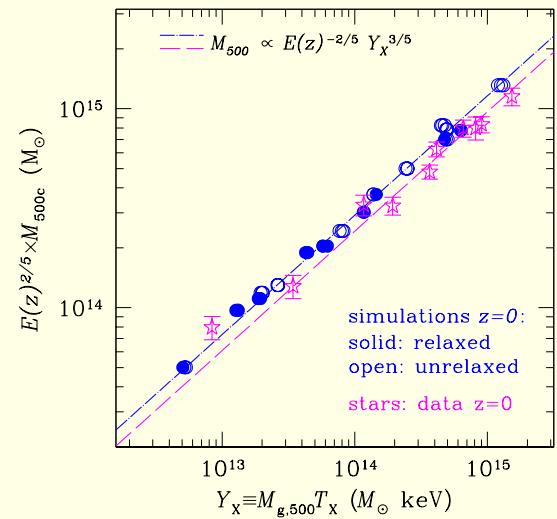
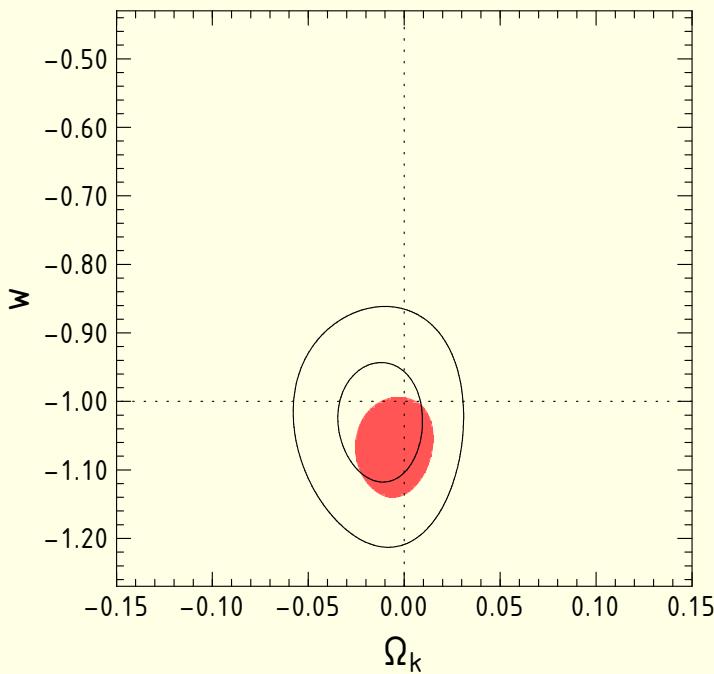
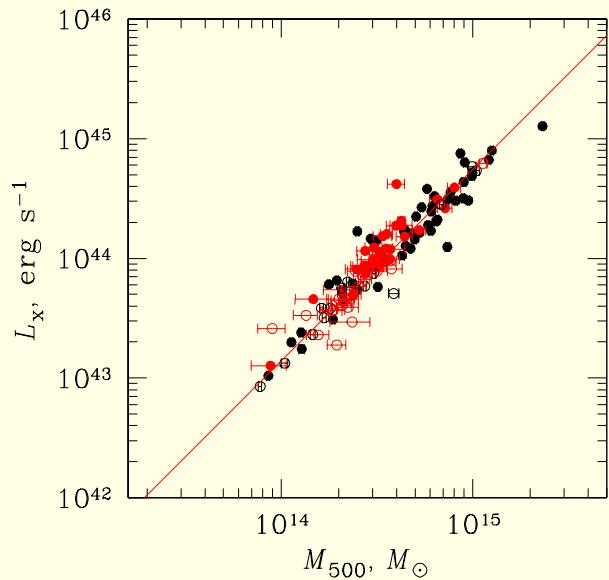
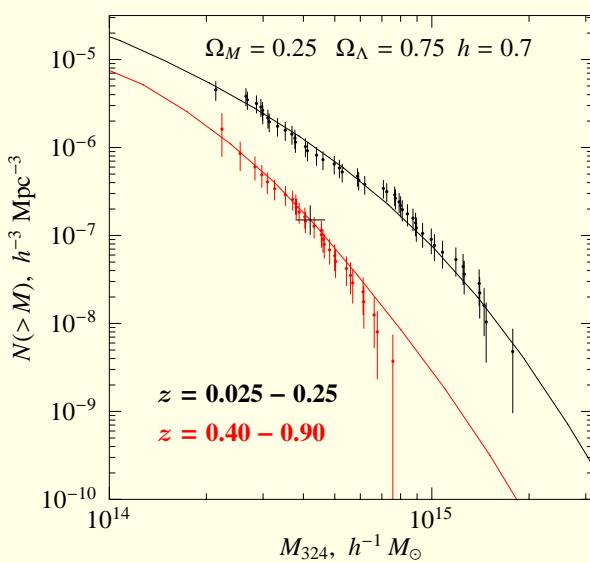
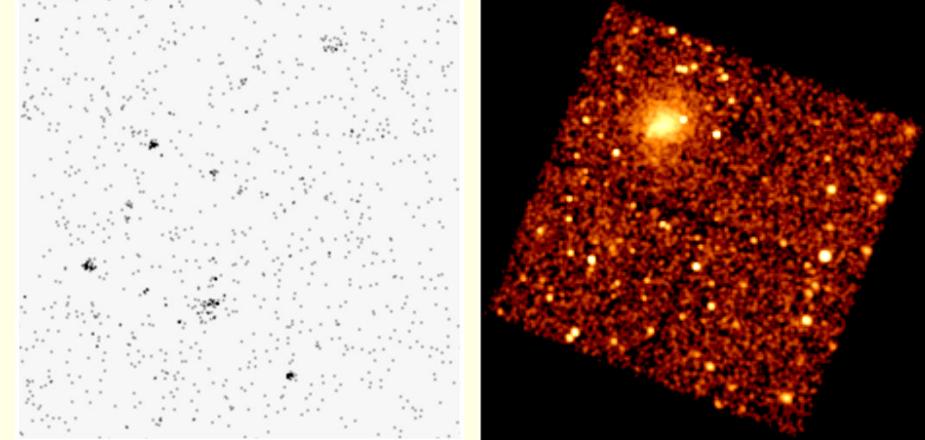
$$\Delta M/M = 9\% \text{ absolute scale: } \rightarrow \Delta w = 0.035$$

$$\Delta M/M = 5\% \text{ at } z = 0.5 \text{ relative scale: } \rightarrow \Delta w = 0.006 \quad (0.10 \text{ for evolution-only})$$

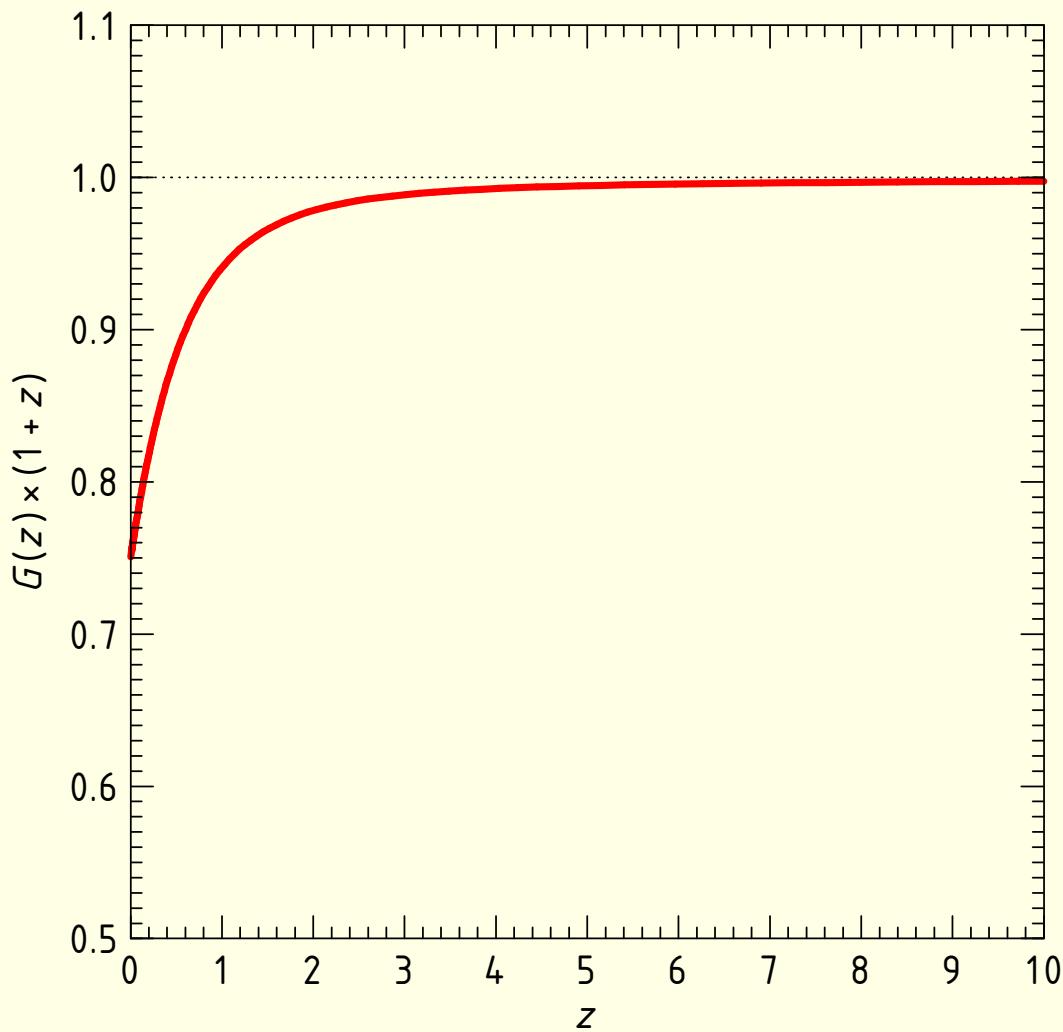
CMB + SN + BAO + clusters



- $\Delta w = \pm 0.05$ (0.07 without cluster data)
- More stable to systematics:
SN systematics: $\Delta w = 0.04 \rightarrow \Delta w = 0.015$ with clusters
Cluster systematics: $\Delta w = 0.035 \rightarrow \Delta w = 0.025$ with SN and BAO

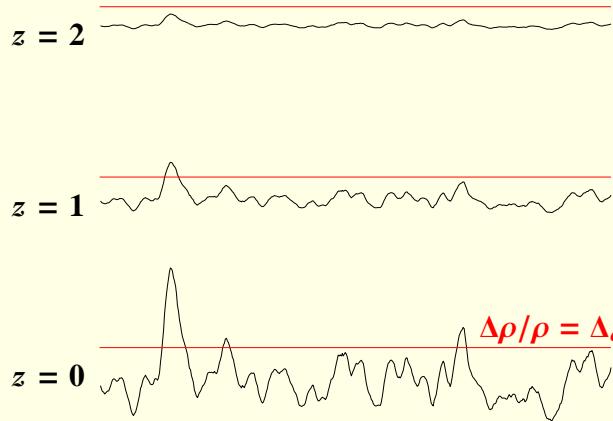


Is it fair to combine σ_8 with CMB?



- Growth rate fixed at $z \gtrsim 2$
- WMAP equivalent to mass function at $z = 1 - 2$

$G(z)$ as dark energy probe



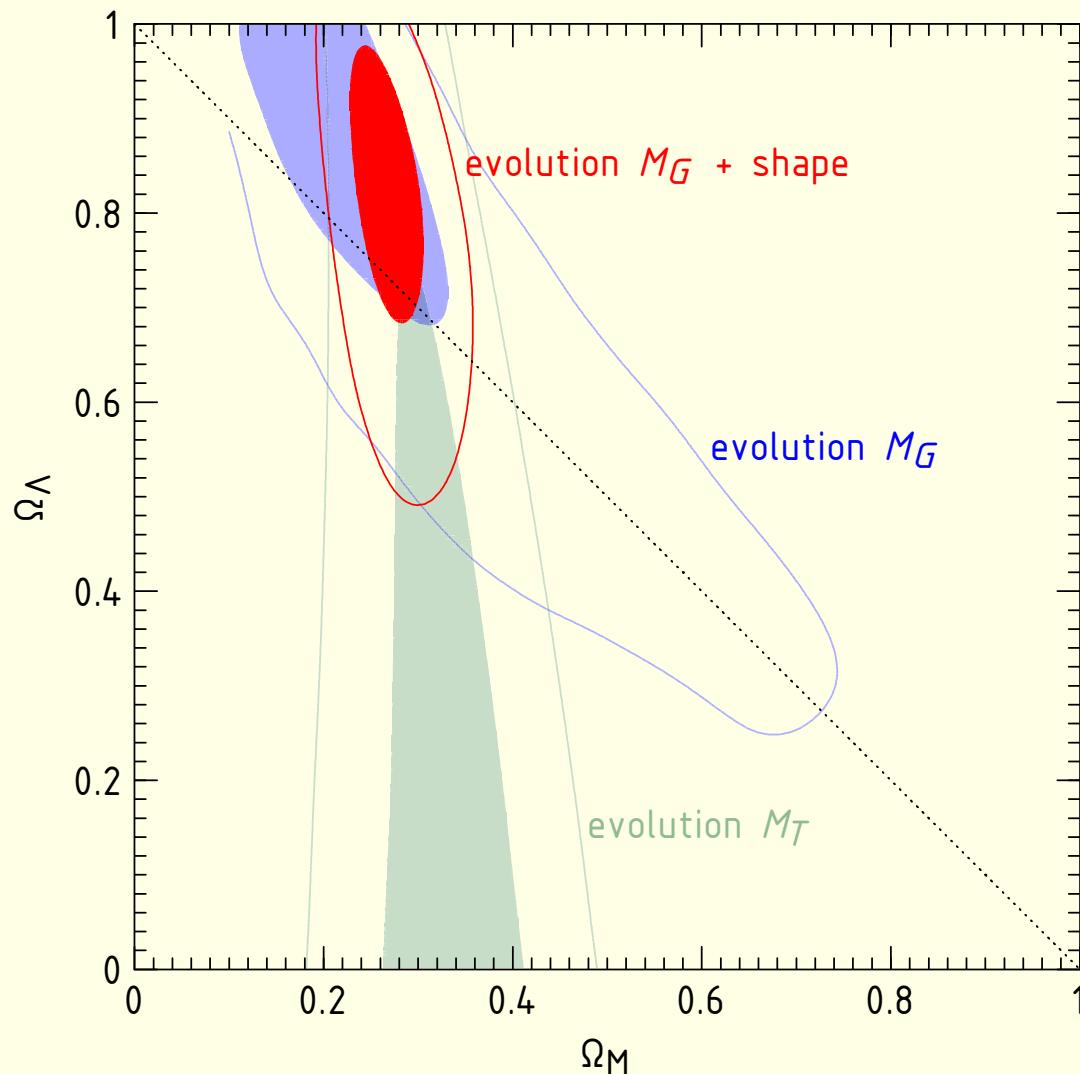
- Linear growth

$$\ddot{G} + 2H(z)\dot{G} - (3/2)H(z)^2\Omega_m(z)G = 0$$

- Non-linear collapse:

Press-Schechter, Sheeth & Torment, Jenkins et al., Tinker et al.

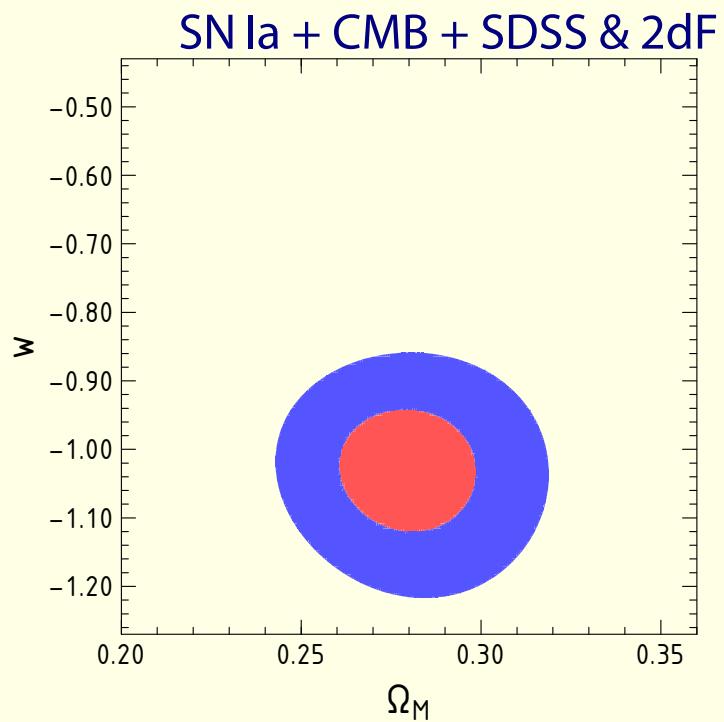
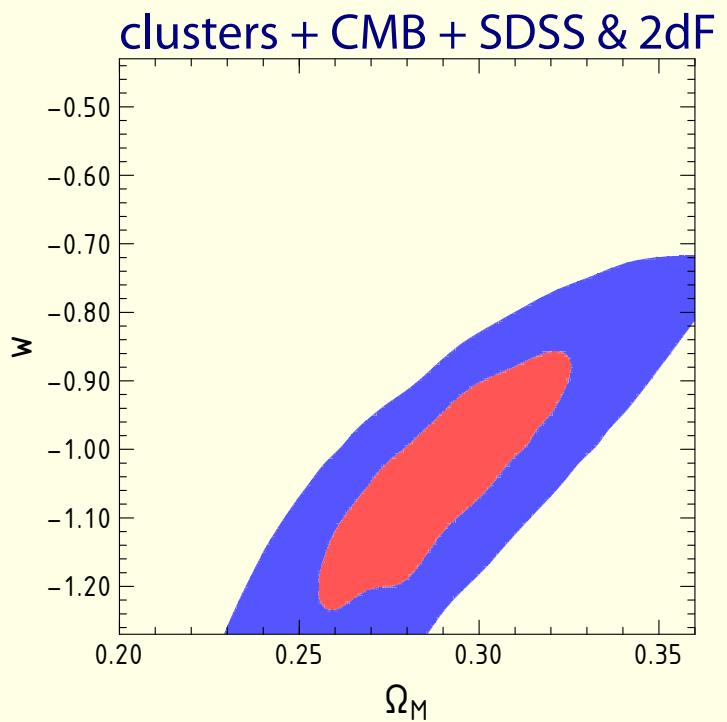
Cluster mass functions



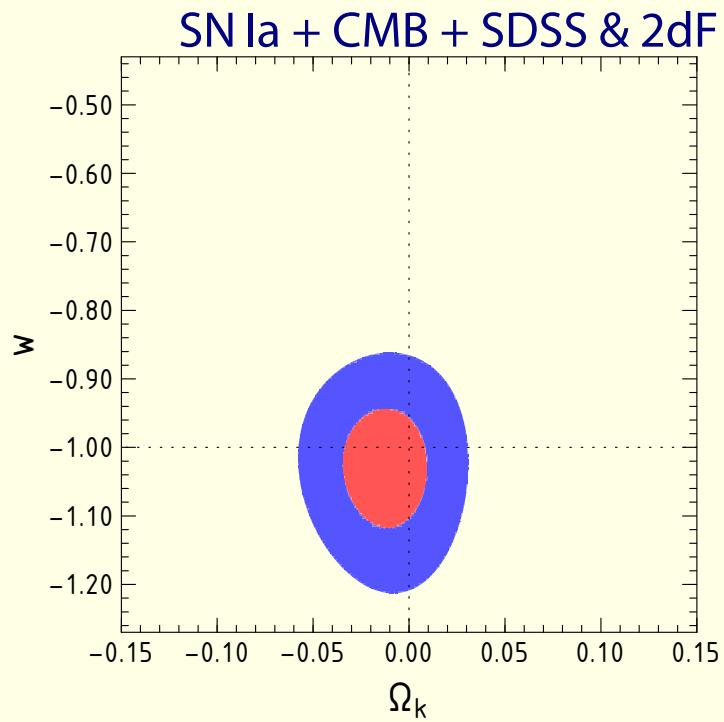
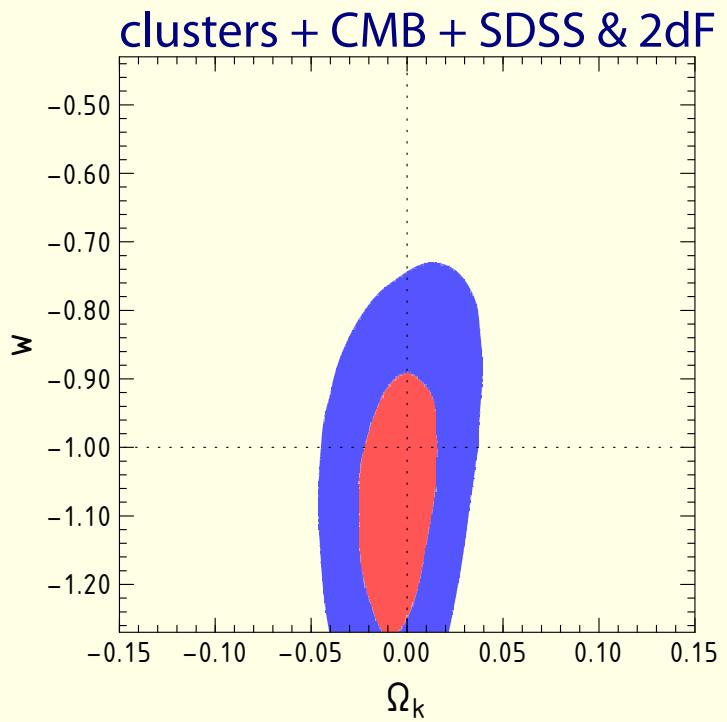
gas: $M_{\text{tot}} = C M_{\text{gas}}$, $M_{\text{gas}} \propto d(z)^{5/2}$

temperature: $M_{\text{tot}} = C T^{3/2} E(z)^{-1}$

Flat

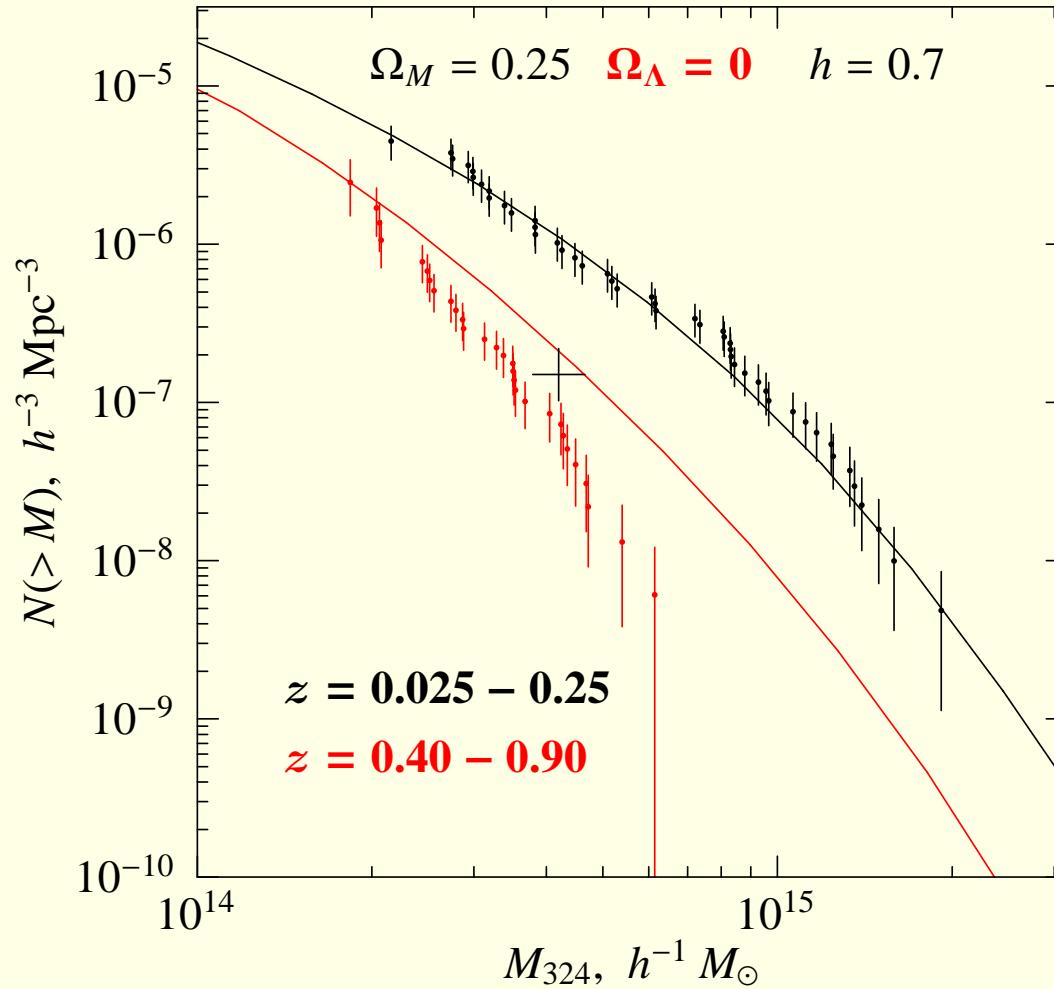


Non-flat



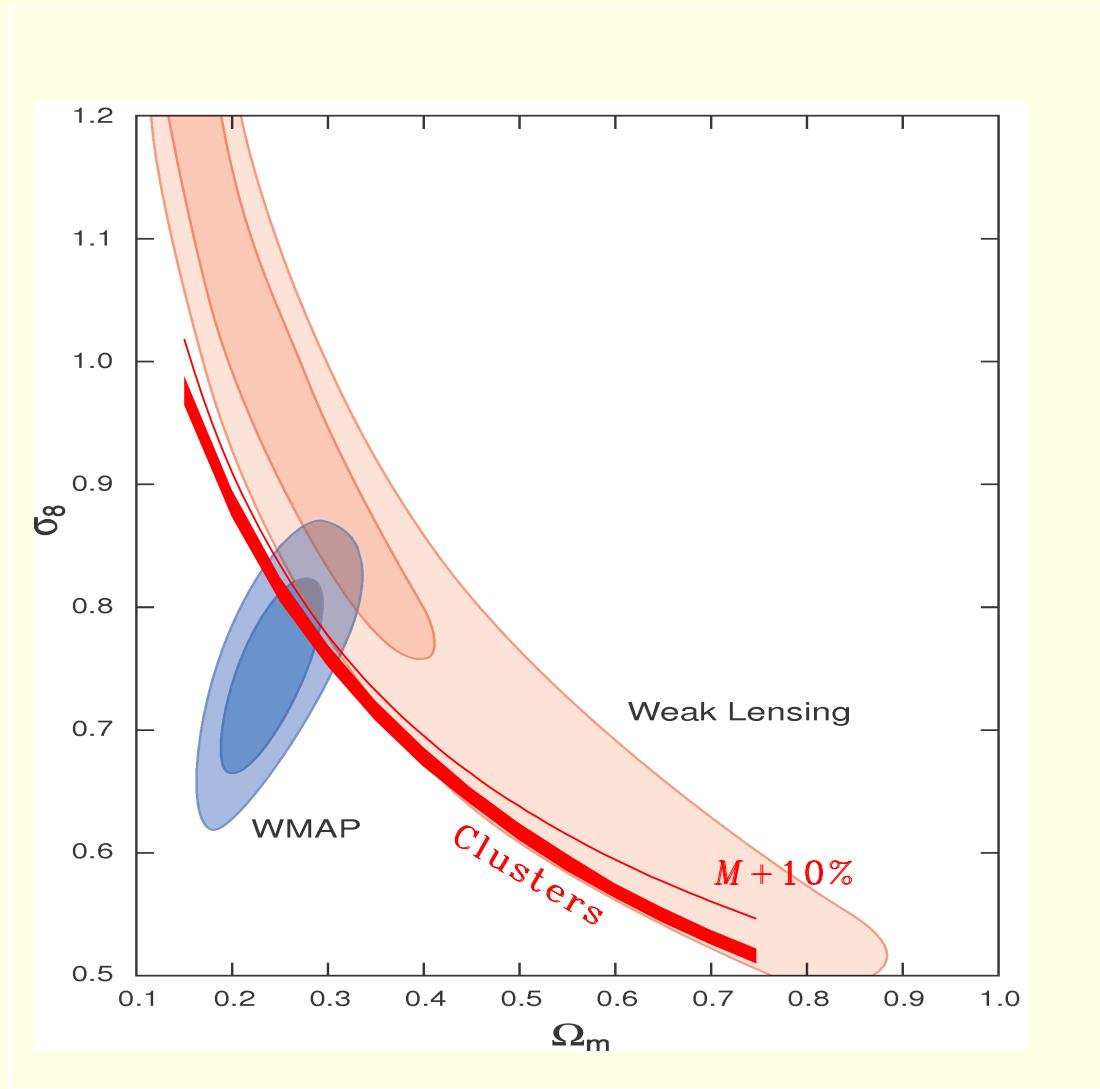
“Trivial highlights”

- Cluster evolution “detects Λ ”:



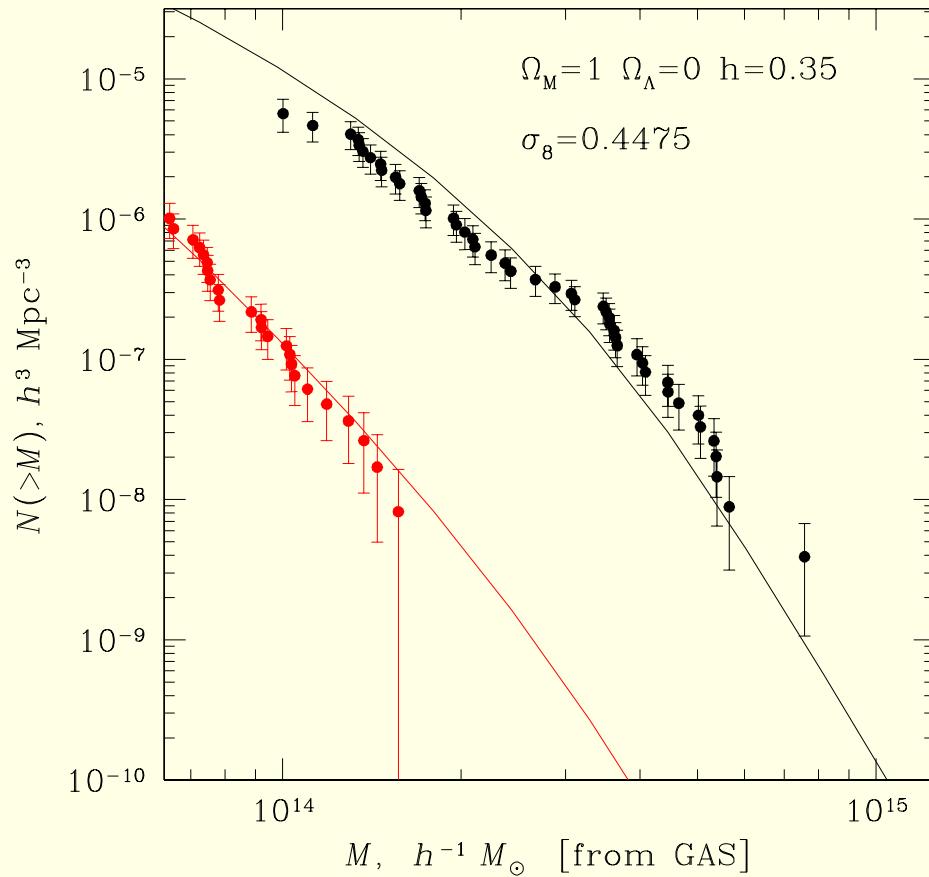
“Trivial highlights”

- Cluster evolution “detects Λ ”.
- gives good σ_8 :



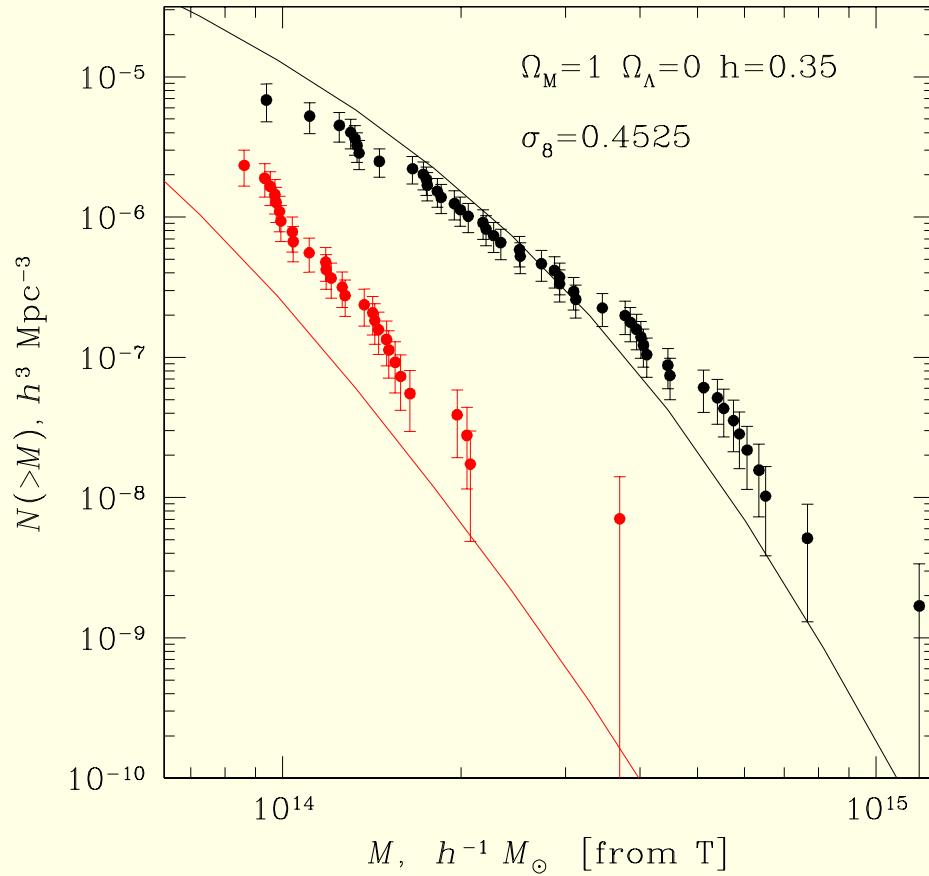
“Trivial highlights”

- Cluster evolution “detects Λ ”.
- gives good σ_8 .
- inconsistent with $\Omega_M = 1$:

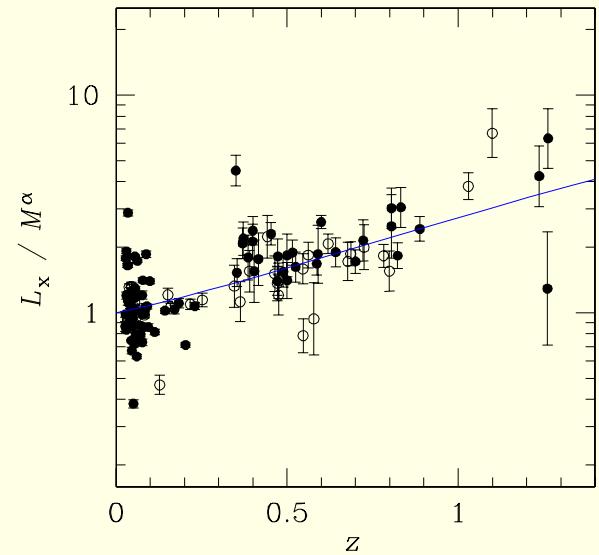
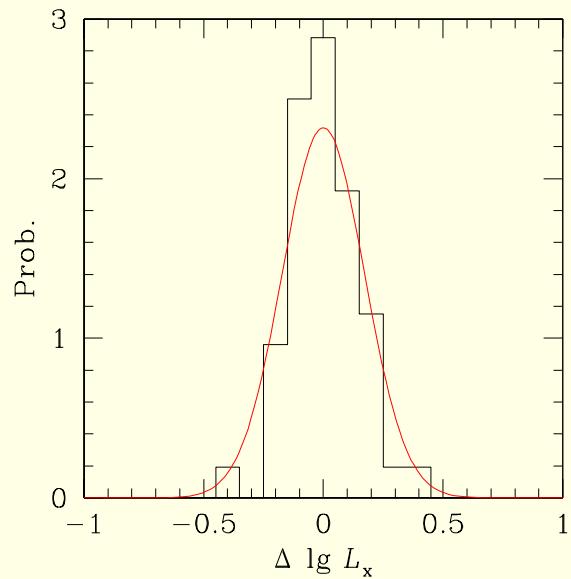
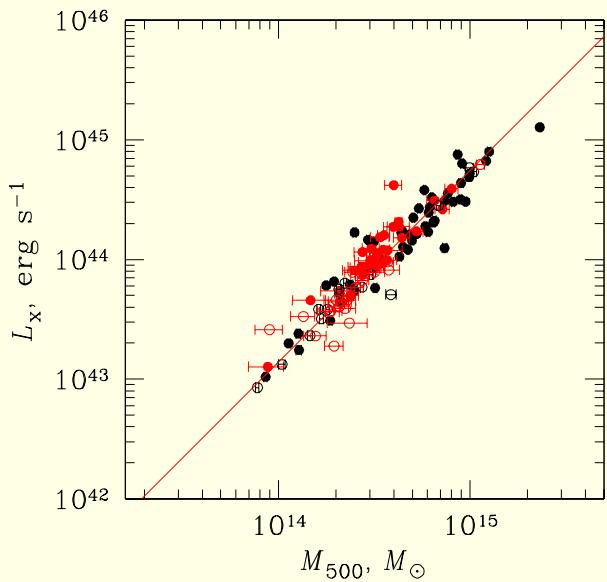


“Trivial highlights”

- Cluster evolution “detects Λ ”.
- gives good σ_8 .
- inconsistent with $\Omega_M = 1$:



Luminosity-Mass relation



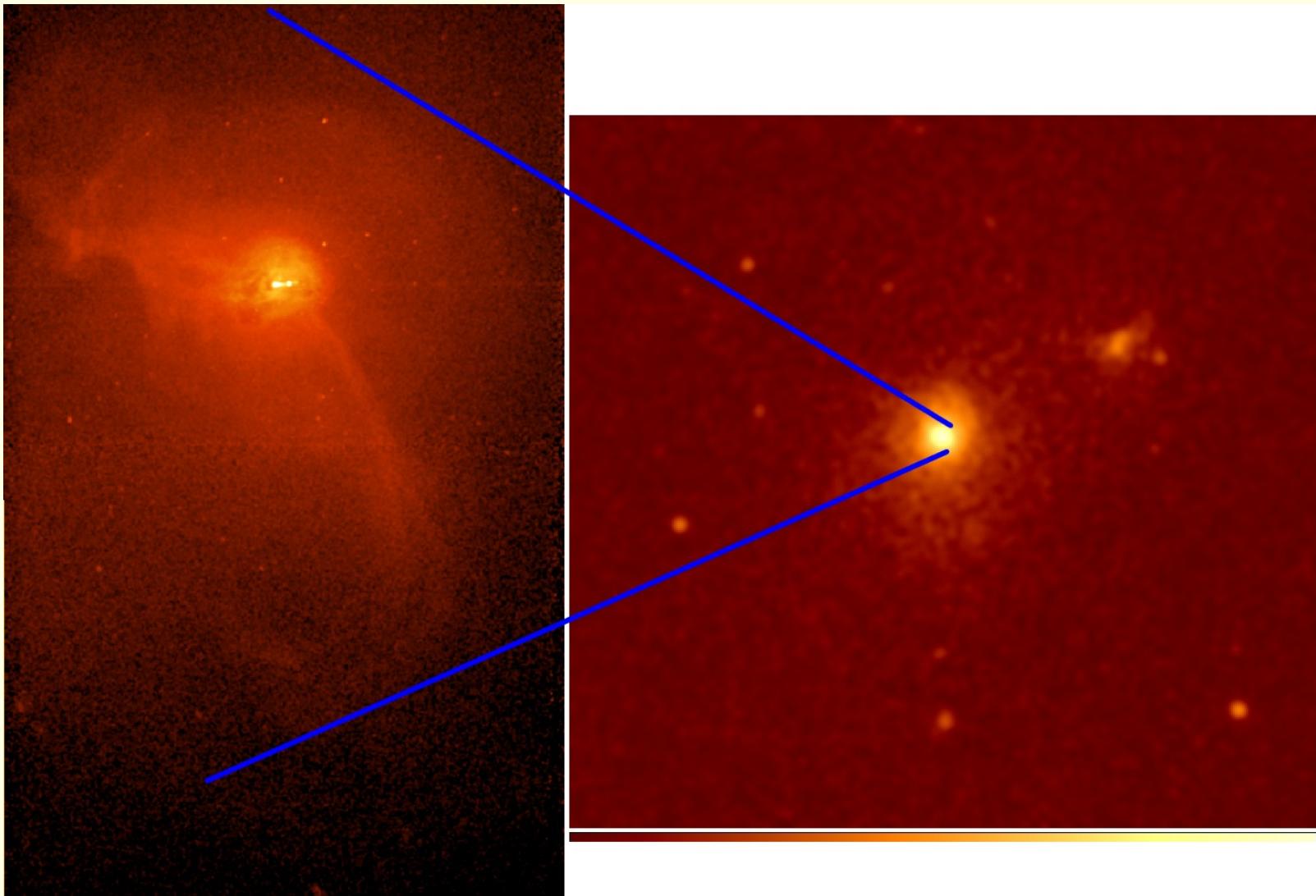
$$\ln L_x = B + A \ln M + \alpha E(z) \pm \sigma$$

$$A = 1.60$$

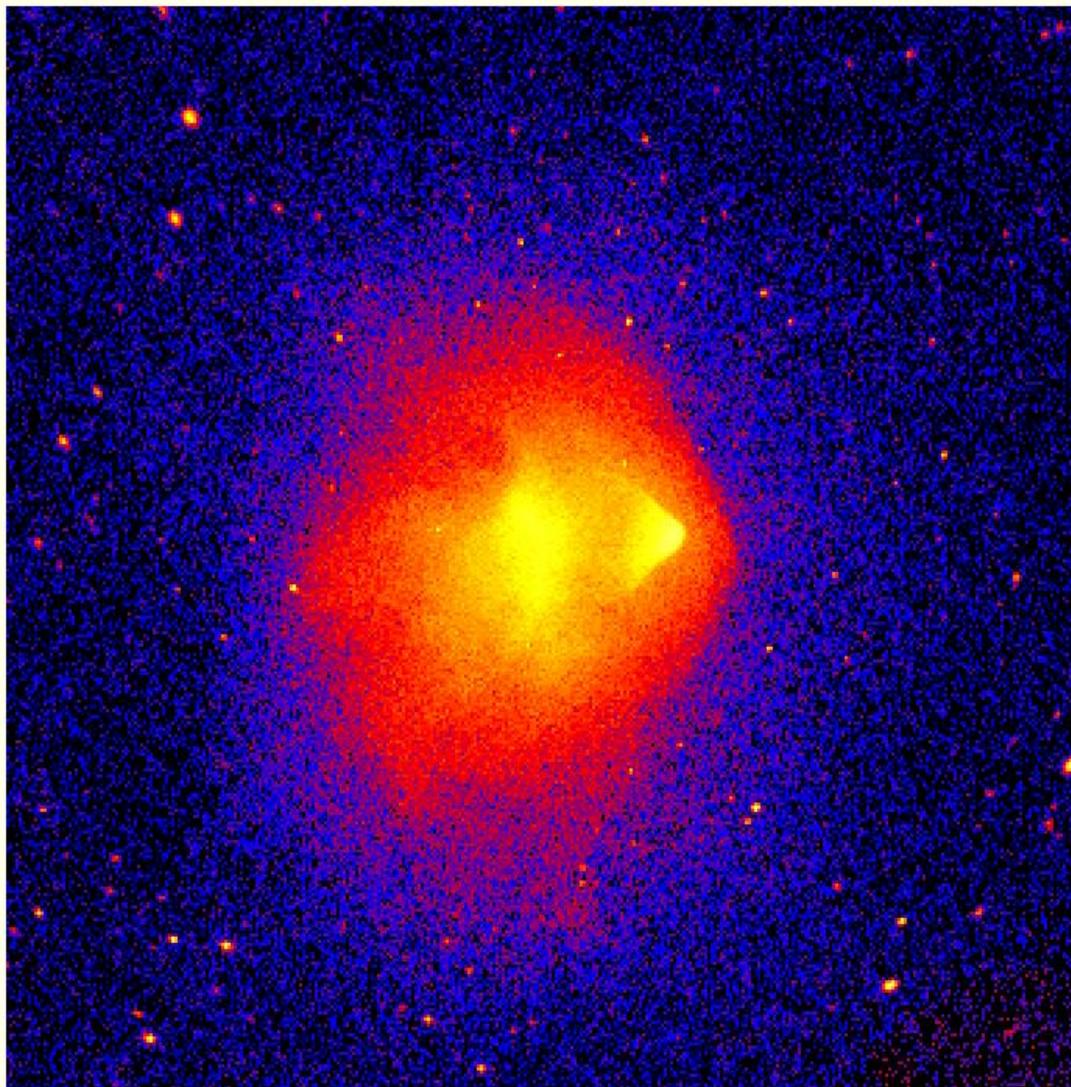
$$\alpha = 1.855$$

$$\sigma = 0.40$$

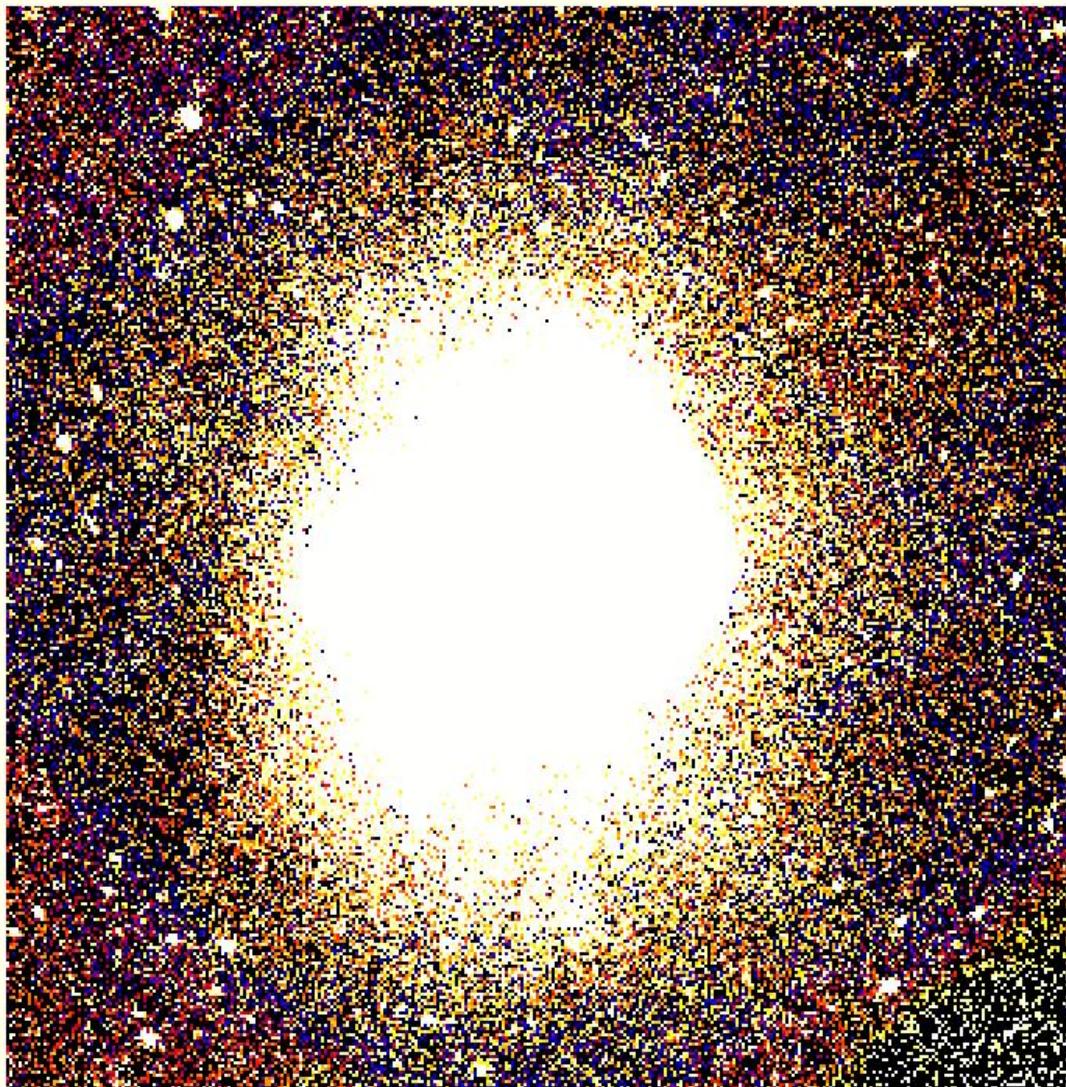
M87



“Bullet Cluster”



“Bullet Cluster”



$\Omega_M - \Omega_\Lambda$ constraints

Cluster evolution + Shape of $N(M)$

